

Mid-frequency Environmental and Acoustic Studies from SW06, and Applications to Asian Littoral Waters

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LONG-TERM GOALS

- (1) To develop a basis for the Navy to make decisions on what environmental parameters to measure, to what spatial and temporal scale they should be measured, and how to best select frequencies for sonar design. Emphasis is on the mid- to high-frequency range defined as frequencies nominally between 1 and 20 kHz.
- (2) A second goal relates to engagement with the Naval Research Laboratory, the Korean Agency for Defense Development (ADD), Hanyang University (HYU), to undertake collaborative research programs in shallow water acoustics in Asian littoral waters.

OBJECTIVES

The primary objective this year was to complete analysis of two sets experimental data Shallow Water 06 (SW06) that were obtained by the PI in August 2006 in collaboration with Dajun Tang of APL-UW and other SW06 participants. A second objective was to participate in experiment off the coast of Korea with NRL, ADD and HYU that occurred in August.

APPROACH

The main item of experimental instrumentation used in SW06, the Moored Receiving Array (MORAY) included a horizontal line array, and two vertical line arrays (at depths 25 and 50 m). As shown in Fig. 1, an acoustic source (1-20 kHz) was deployed at depth 40 m from the stern of the R/V *Knorr*, and signals were recorded on the MORAY. The location of the MORAY (39.0245 N, 73.0377 W, depth 80 m) defined the central (mid-frequency) site for SW06 experimental observations, and propagation measurement were made at fixed stations that allowed for the sampling of acoustic propagation effects at different ranges and directions with respect to the MORAY.

Key individuals involved in SW06 data analysis include Jeewoong Choi (HYU) in relation to propagation analysis using parabolic equation (PE) methods, John Goff (U. Texas) in relation to the seabed geology and geomorphology of SW06, and Neil Williams (U. Miami) in relation to air-sea conditions during SW06.

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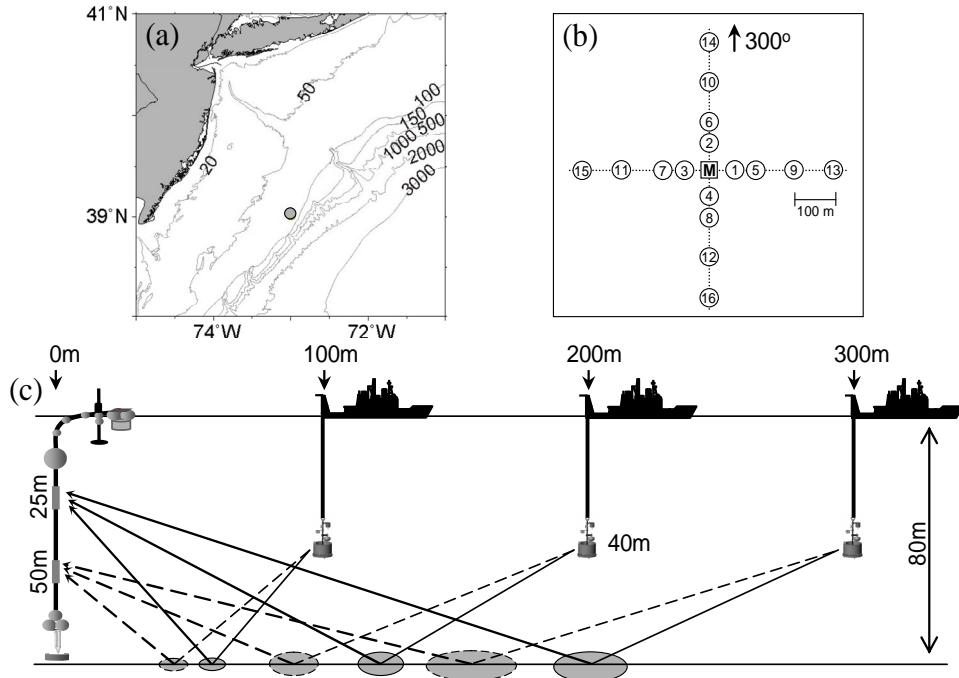


Figure 1. (a) General location of SW06. (b) Location of the acoustic receiving system MORAY (M in center of fig.) with respect to 16 of the 20 acoustic transmission stations. Each transmission station represents the precise location of the stern of the R/V Knorr (from which the APL-UW acoustic source was suspended.) The direction of 300° is noted. (c) Representative bottom-interacting ray paths and Fresnel zones (shaded) associated with stations at different ranges.

WORK COMPLETED

The work completed this year concerning SW06 experimental data primarily involves two lines of inquiry originating in part from discussions at the February 2008 SW06 Workshop in Florida.

One is on the analysis of seabed reflection as a function of bottom grazing angle and the related study of so-called the R-reflector. The R-reflector is a specific, readily identifiable, single interaction observation of the R horizon, a regionally-observed positive-impedance reflector [1]. Over the SW06 central site the R horizon is at a nominal depth of 22 m based on 2-way travel time from 1-4 kHz vertical incidence chirp data. The R horizon along our particular SW06 transect lines is relatively flat, changing by at most 3.5 msec (~3 m) over a span of 1000 m. Results of this work are summarized in the September 2008 issue of *JASA Express Letters* in Choi, *et al.*, 2008.

The other is on study of excess attenuation from near surface bubbles. Here an experimental geometry similar to that shown in Fig. 1 was used except the focus was on the ray paths that interacted with the sea surface. Excess attenuation measurements were compared with Air-Sea measurements derived from the two (Yankee and Romeo) Air-Sea Interaction Spar (ASIS) buoy moorings from the University of Miami. The Yankee mooring was 1.5 km from the MORAY, and the Romeo mooring was 11 km shoreward from the MORAY.

Results of this work are summarized in the September 2008 issue of *JASA Express Letters* in Dahl *et al.*, 2008.

RESULTS

The key results from the R-reflector study are summarized in Fig. 2. The specific arrival associated with the R-reflector is readily seen in the 2-kHz data of Fig. 2 (d), however, the amplitude of this arrival has been reduced to below the background level for the simultaneously measured 6-kHz data of Fig. 2 (e) (and indeed the all simultaneously measured data at frequencies 6-20 kHz.) In terms of inversion, the R-reflector travel time analysis yielded an estimate of the thick layer depth to be 22 ± 1 m within which the compressional wave speed and attenuation were 1630 ± 20 m/s and 0.05 ± 0.01 dB/m/kHz, respectively. Forward modeling using the parabolic equation algorithm reproduced well the arrival structure at 2 kHz as shown in Figs. 2 (f-g).

The acoustic bottom-interacting measurements reported in Choi, *et al.*, (2008) provide a clear demonstration of the role of stratigraphic constraints and ground truth data on sediment bulk physical properties, on both geoacoustic inversion and acoustic forward modeling. Furthermore, our results are reasonably consistent with the co-located (SAMS) direct measurements of sediment sound speed to a depth of 1.6 m [2]

The key results from the bubble attenuation study from SW06 are summarized in Figs. 3 and 4. In Fig. 3 it can be seen that statistically significant observations of bubble attenuation are made on Aug 15 during a period of high wind speed and which tend to increase with frequency (the lower wind speed case of Aug. 10 is shown for reference.). These observations are modeled with results shown in Fig. 4.

Five conclusions emerge from our study: (1) bubble-mediated attenuation does not become statistically observable until wind speeds exceed the 8-10 m/s range. This is consistent with previous studies made with smaller frequency range. (2) For higher wind speeds a frequency dependent attenuation goes approximately as f^2 where f is frequency. This reflects an underlying bubble size distribution that goes as a^{-5} where a is bubble radius, and is consistent with modeling assumptions. (3) Attenuation measurements decrease with increasing grazing angle which supports the postulate that, in an averaged sense, attenuation arises from a thin near-surface layer of bubbles of depth scale $L = O(1)$ m. (4) The precision in specifying oceanic bubble void fraction is arguably limited to its magnitude, yet changes in attenuation scale directly with void fraction as shown by the results of the factor of two changes in void fraction (Fig. 4). Finally, (5) the two ASIS wind speed measures, equally valid in their representation of average open-water air-sea conditions, differed by ~ 2 m/s over their respective 30 min. averages. This has cautionary implications for empirical models for bubble attenuation that are a strong function of wind speed.

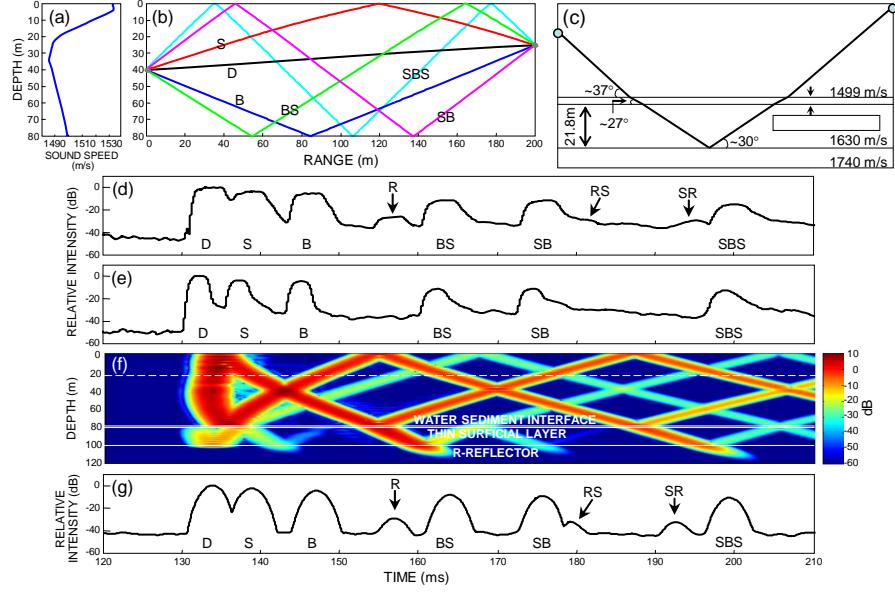


Figure 2. (a) Representative sound speed profile for 10 Aug, 11:07 UTC (b) Corresponding ray diagram for a source at 40 m, 25-m receiver depth and range 200 m, showing the first 6 eigenrays.

The 3rd arriving eigenray is the bottom bounce path (B) for which an estimate of bottom loss estimates were made. Other water-borne paths are the direct (D), surface (S), bottom-surface (BS), surface-bottom (SB), and surface-bottom-surface (SBS). (c) An illustration of the sediment-borne path associated with the R horizon (R); the angles noted apply to case of source at 40 m, 25-receiver depth and range 200 m. (d) Time series of received level for 2 kHz center frequency, based on the average of 20-ping transmissions made on 10 Aug at 10:00 UTC, with acoustic source at station 10 as shown in Fig. 1(b). (e) Simultaneously measured time series of received level for 6 kHz center frequency; here the R path has vanished into the background intensity level formed by time spreading of other paths and sediment attenuation. (f) PE-simulated acoustic field (center frequency 2 kHz) for this geometry based on geoacoustic parameters in Choi, et al. (2008). (g) PE-simulated time series for a source depth at 40 m, receiver depth 25 m and range 200 m, showing the R-reflector multi-path (R) and additional multi-path species of R-reflector-surface (RS) and surface-R-reflector (SR). Noise has been added to the time series to mimic the nominal, expected ratio for signal-to-background level.

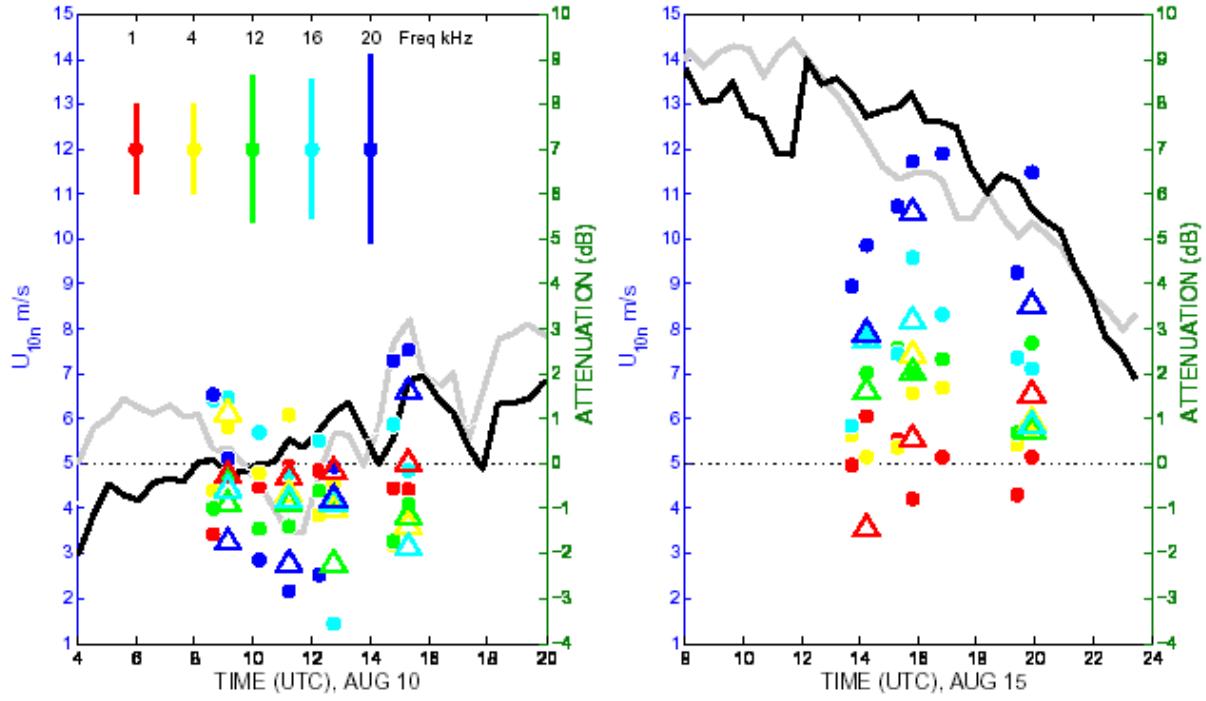


Figure 3. Summary of attenuation measurements at 1, 4, 12, 16 and 20 kHz, for Aug. 10 (left) and Aug. 15 (right), plotted against the Yankee (black) and Romeo (gray) wind speed measurements from the ASIS moorings. Aug. 10 measurements correspond to grazing angle 16° (closed-circle) and 22° (open triangle); Aug. 15 measurements follow same convention with grazing angles increased by $\sim 1^\circ$. Representative frequency-dependent error bars are shown in the left plot and apply to both grazing angles. Note that each plot has dual vertical axes and the dotted horizontal line identifies a 0-dB reference but otherwise has no relation to wind speed. For reference, sunrise and sunset are 09:50 and 23:50, respectively

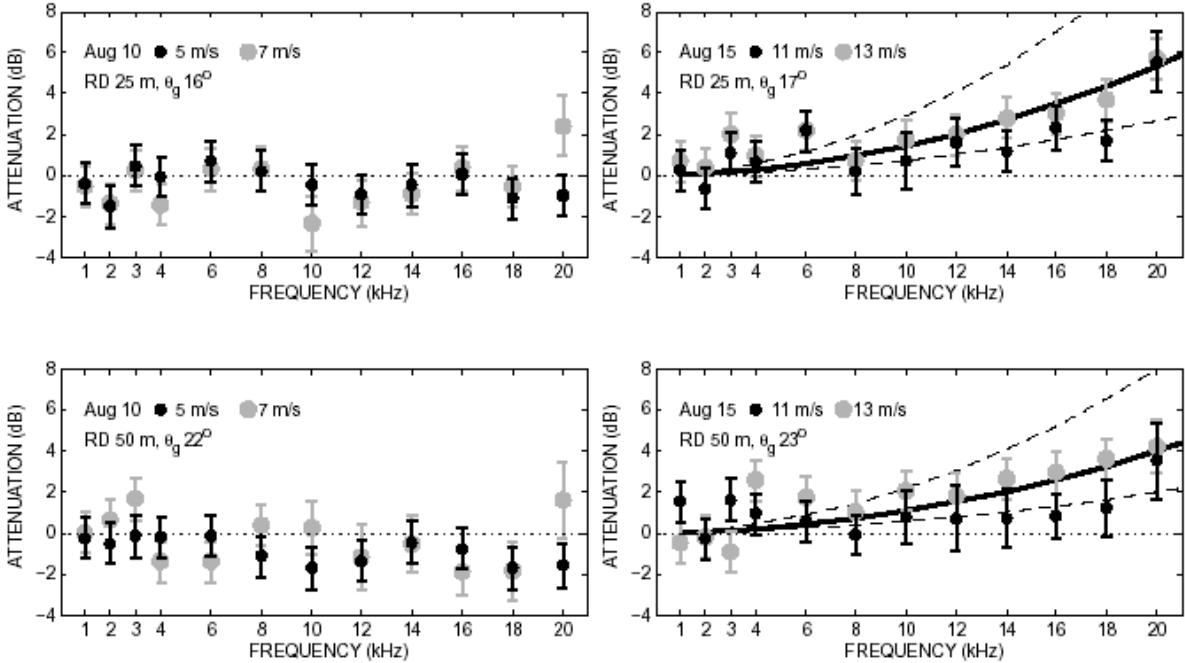


Figure 4. Summary of attenuation measurements made on Aug. 10 (left plots) and Aug. 15 (right plots) as averaged into the wind speed classes defined in the text. Model for measurements on Aug. 15 (thick, black line) uses a void fraction of 6.5×10^{-7} , with dashed lines representing the same model but with void fraction varying by a factor of 2.

IMPACT/APPLICATIONS

The SW06/LEAR data set, with its emphasis on simultaneous, co-located environment and acoustic measurements, will assist the Navy in making rational decisions on what environmental parameters to measure, to what spatial and temporal scale they should be measured, and how to best select frequencies for sonar design. The bubble attenuation measurements as depicted in Figs. 3 and 4 will provide a valuable benchmark with which to compare empirical sonar models with, such as SRFLOS from the OAML model set.

RELATED PROJECTS

This research is integrated together with those from several PIs involved in the SW06/LEAR program.

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